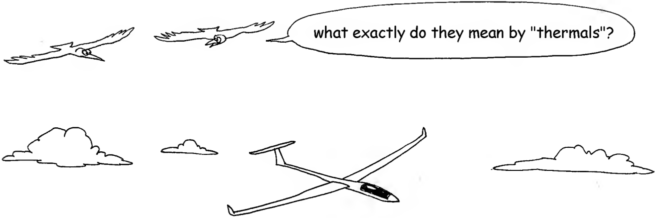
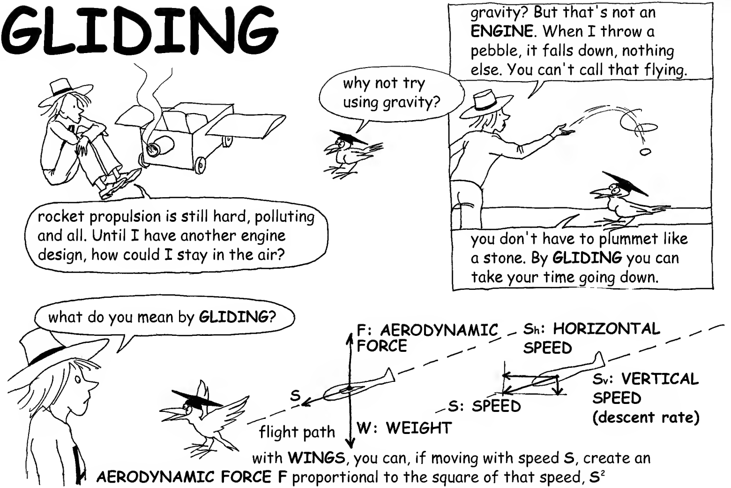
http://savoir-sans-frontieres.com

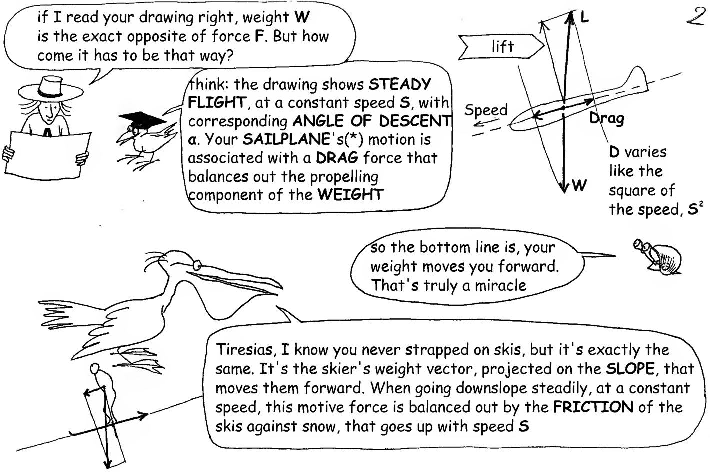


Jean-Pierre Petit, 2008

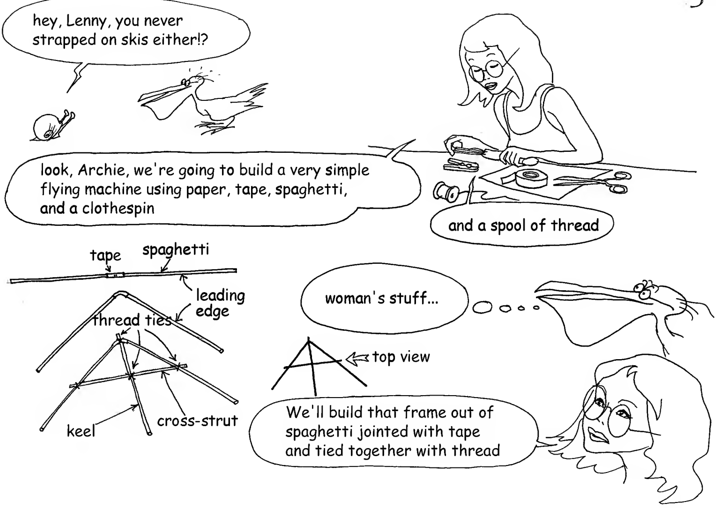
FLIGHTY MECHANICS

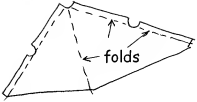
Translation: Pau Amma, 2011

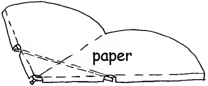

GLIDING
rocket propulsion is still hard, polluting and all. Until I have another engine design, how could I stay in the air?
why not try using gravity?
gravity? But that's not an ENGINE. When I throw a pebble, it falls down, nothing else. You can't call that flying.
you don't have to plummet like a stone. By GLIDING you can take your time going down.
what do you mean by GLIDING?
F: AERODYNAMIC FORCE
S
flight path
W: WEIGHT
Sh: HORIZONTAL SPEED
Sv: VERTICAL SPEED (descent rate)
S: SPEED
with WINGS, you can, if moving with speed S, create an AERODYNAMIC FORCE F proportional to the square of that speed, S²

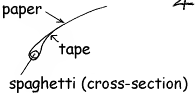


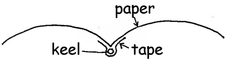
(*) Also called "glider", although that term is more commmonly applied to hang gliders or paragliders. (See below pages 5 and 36.)


hey, Lenny, you never strapped on skis either!?
look, Archie, we're going to build a very simple flying machine using paper, tape, spaghetti, and a clothespin
and a spool of thread
tape
spaghetti
leading edge
thread ties
keel
cross-strut
woman's stuff...
top view
We'll build that frame out of spaghetti jointed with tape and tied together with thread

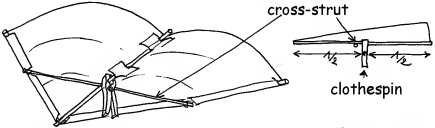


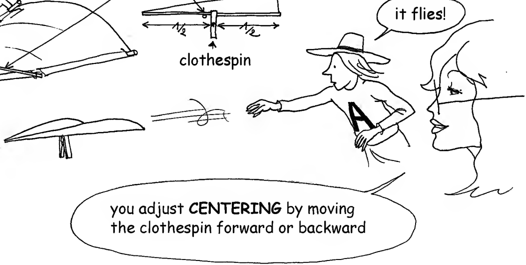




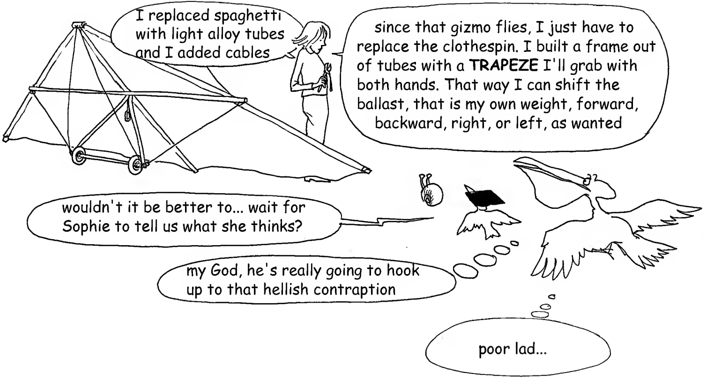


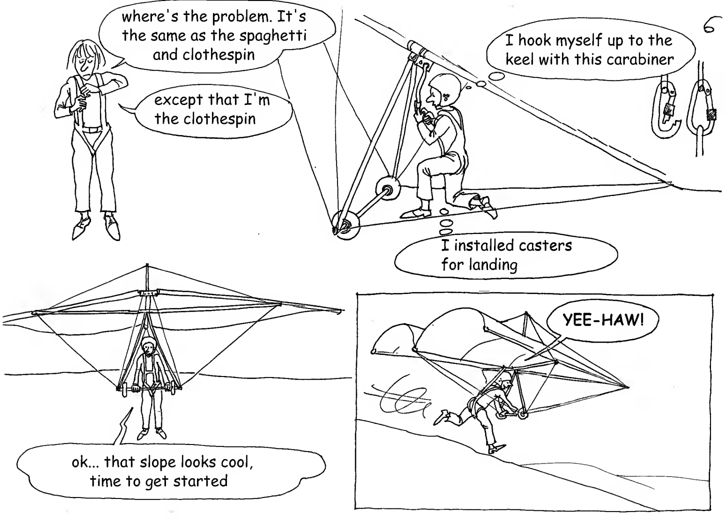
attaching the wing to the tube frame

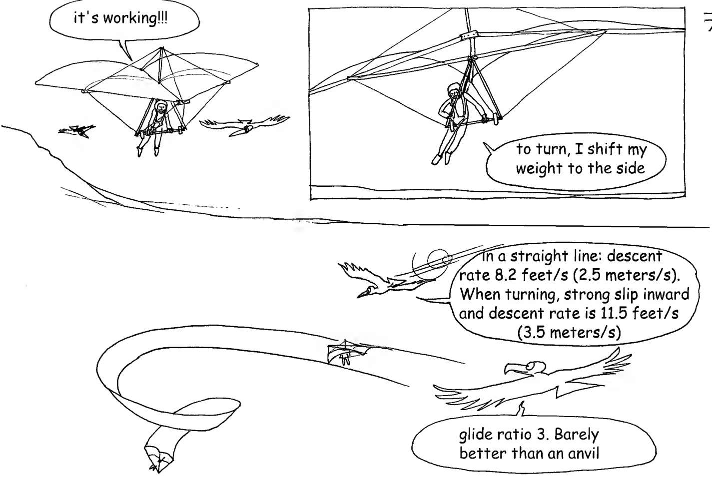


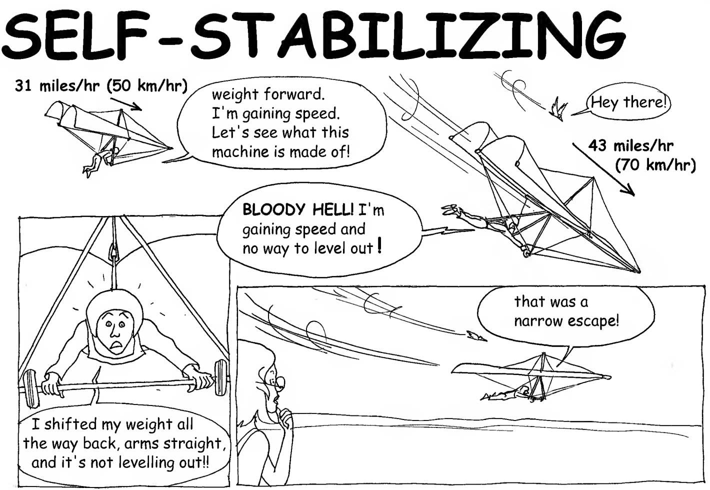


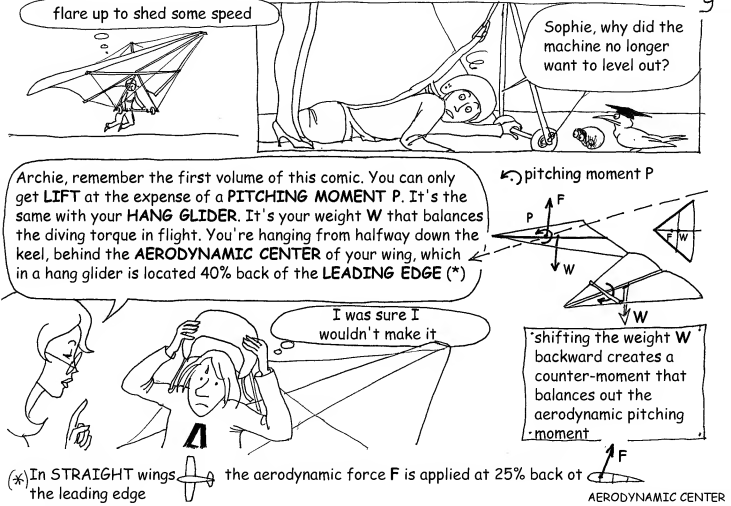
HANG GLIDER

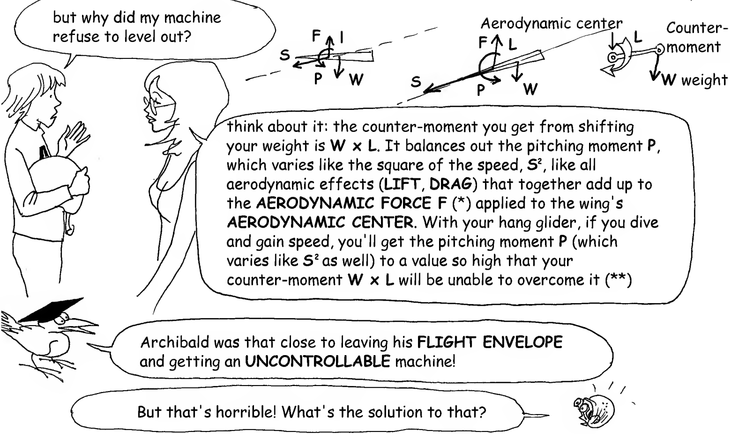

I replaced spaghetti with light alloy tubes and I added cables
since that gizmo flies, I just have to replace the clothespin. I built a frame out of tubes with a **TRAPEZE** I'll grab with both hands. That way I can shift the ballast, that is my own weight, forward, backward, right, or left, as wanted
wouldn't it be better to... wait for Sophie to tell us what she thinks?
my God, he's really going to hook up to that hellish contraption
poor lad...


where's the problem. It's the same as the spaghetti and clothespin
except that I'm the clothespin
I hook myself up to the keel with this carabiner
I installed casters for landing
ok... that slope looks cool, time to get started
YEE-HAW!


it's working!!!
to turn, I shift my weight to the side
in a straight line: descent rate 8.2 feet/s (2.5 meters/s). When turning, strong slip inward and descent rate is 11.5 feet/s (3.5 meters/s)
glide ratio 3. Barely better than an anvil

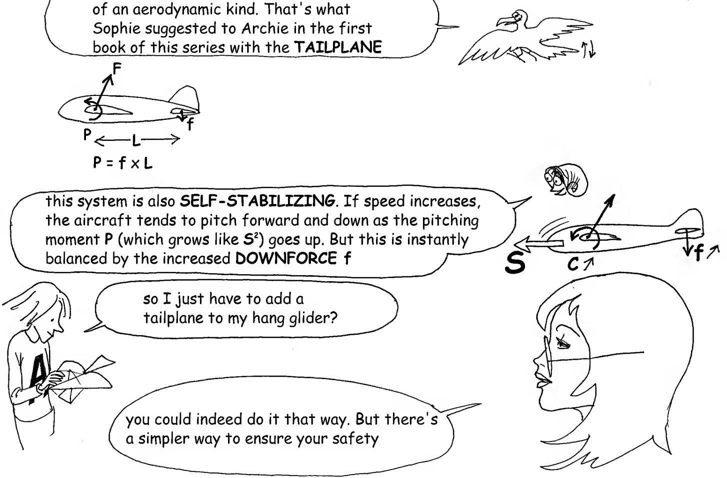

SELF-STABILIZING
31 miles/hr (50 km/hr)
weight forward. I'm gaining speed. Let's see what this machine is made of!
Hey there!
43 miles/hr (70 km/hr)
BLOODY HELL! I'm gaining speed and no way to level out!
I shifted my weight all the way back, arms straight, and it's not levelling out!!
that was a narrow escape!

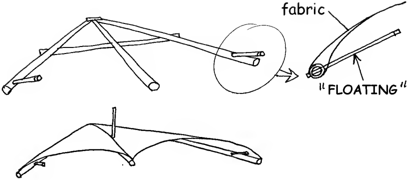

flare up to shed some speed
Sophie, why did the machine no longer want to level out?
Archie, remember the first volume of this comic. You can only get **LIFT** at the expense of a **PITCHING MOMENT P**. It's the same with your **HANG GLIDER**. It's your weight **W** that balances the diving torque in flight. You're hanging from halfway down the keel, behind the **AERODYNAMIC CENTER** of your wing, which in a hang glider is located 40% back of the **LEADING EDGE** (*)
pitching moment P
F
P
W
F
W
W
I was sure I wouldn't make it
shifting the weight **W** backward creates a counter-moment that balances out the aerodynamic pitching moment
(*) In STRAIGHT wings the leading edge
the aerodynamic force **F** is applied at 25% back ot
F
AERODYNAMIC CENTER

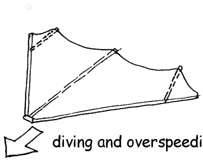


(*) Some textbooks call this **RESULTANT AERODYNAMIC FORCE**, abbreviated to **R**

(**) Lack of awareness of this hazard caused many accidental deaths through the 1970s


an aerodynamic problem requires a solution of an aerodynamic kind. That's what Sophie suggested to Archie in the first book of this series with the **TAILPLANE**
F
f
P
L
$P = f \times L$
this system is also **SELF-STABILIZING**. If speed increases, the aircraft tends to pitch forward and down as the pitching moment **P** (which grows like S^2) goes up. But this is instantly balanced by the increased **DOWNFORCE f**
S
C ↗
f ↗
so I just have to add a tailplane to my hang glider?
you could indeed do it that way. But there's a simpler way to ensure your safety

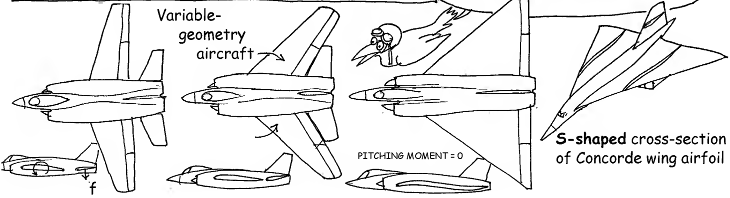




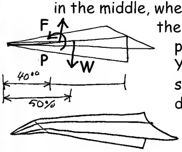
diving and overspeeding wing

these devices, called "**FLOATINGS**", do not touch the sail in normal flight, but if overspeeding or nosediving become dangerous, they keep the back of the sail raised, forcing automatic leveling out (*)

Aircraft with rigid delta wings are made self-stabilizing (flying with pitching moment = 0) by merging the tailplane into the main wings and giving the airfoil a **S-shaped** cross-section

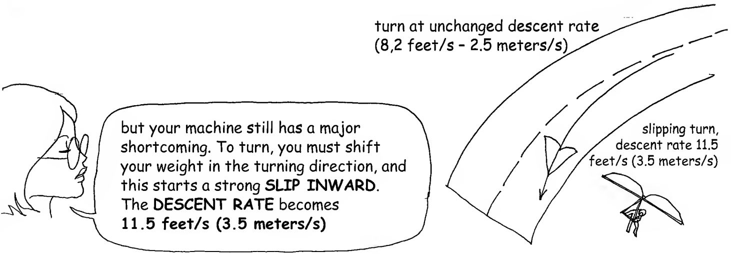


S-shaped cross-section of Concorde wing airfoil



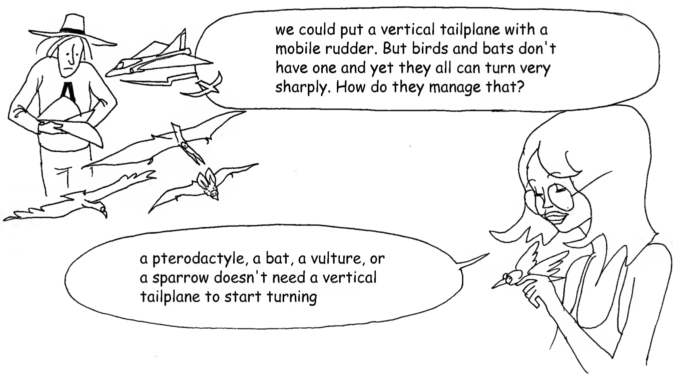
a traditional paper dart flies like a hang glider. The center of gravity is obviously in the middle, whereas the **AERODYNAMIC CENTER** is 40% along the **CHORD** of the airfoil. The counter-moment from the weight balances out the pitching moment from the lift. In a deep dive, it won't level out. You can make the airfoil self-stabilizing by folding down the nose slightly and by raising the tail equally slightly, This makes the dart S-shaped and lets it (among other things) fly more slowly.

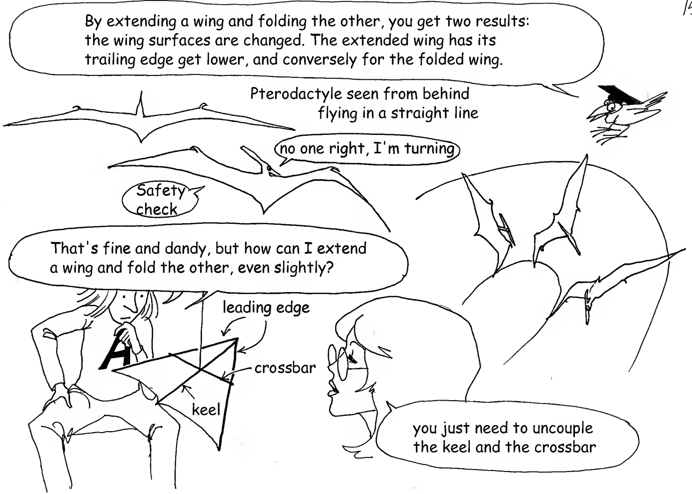
The Management

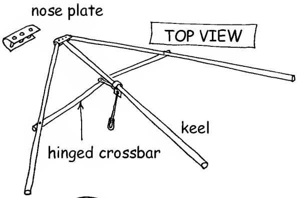


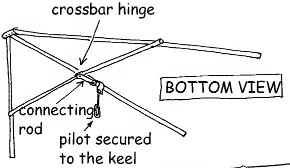
(*) these simple devices were shown at once to work perfectly.

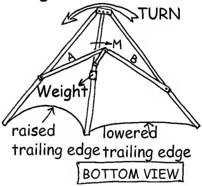
HOW DO BIRDS MANAGE TO TURN?

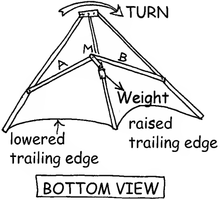


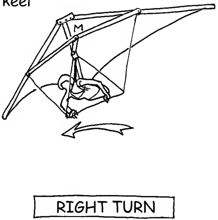

By extending a wing and folding the other, you get two results: the wing surfaces are changed. The extended wing has its trailing edge get lower, and conversely for the folded wing.
Pterodactyle seen from behind flying in a straight line
no one right, I'm turning
Safety check
That's fine and dandy, but how can I extend a wing and fold the other, even slightly?
leading edge
crossbar
keel
you just need to uncouple the keel and the crossbar





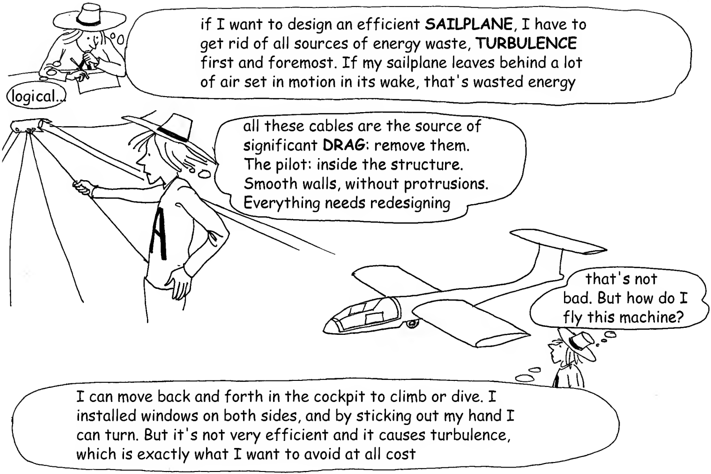


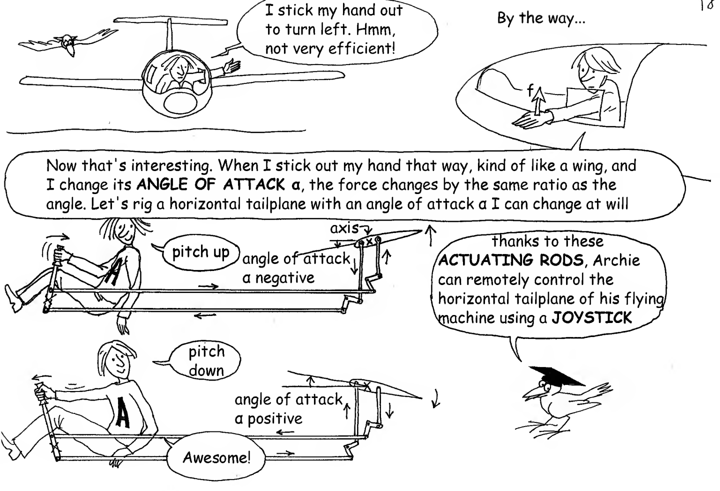


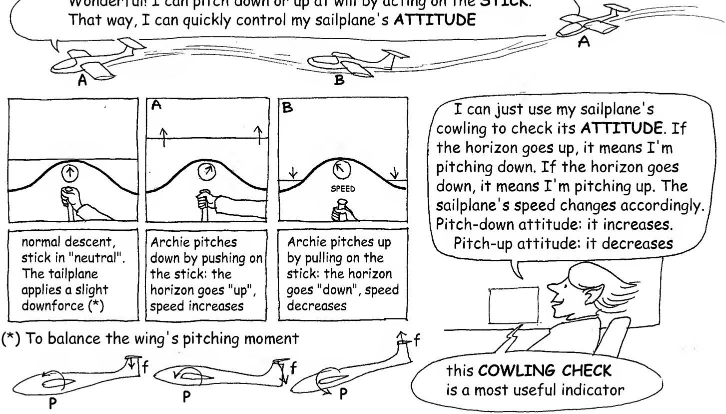


This very ingenious design called "floating crossbar" lets the pilot, by shifting weight, to move the keel from the hinge M of the half-crossbars A and B, which have the same length. Moving an inch or two (a few centimeters) lets you make tight turns.

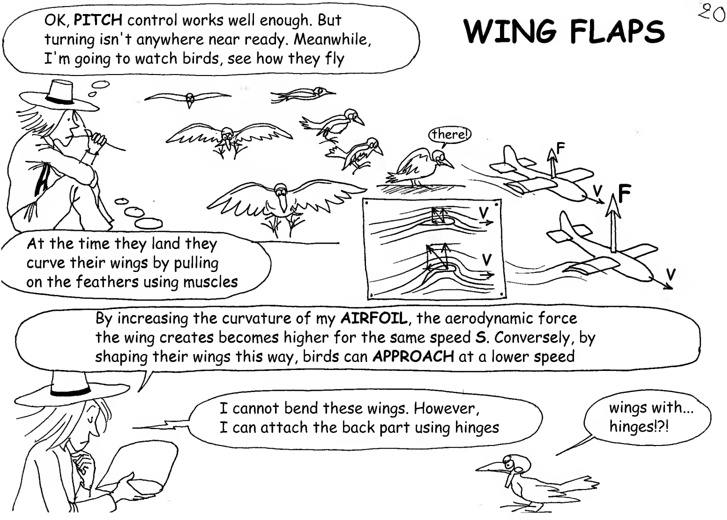
The Management

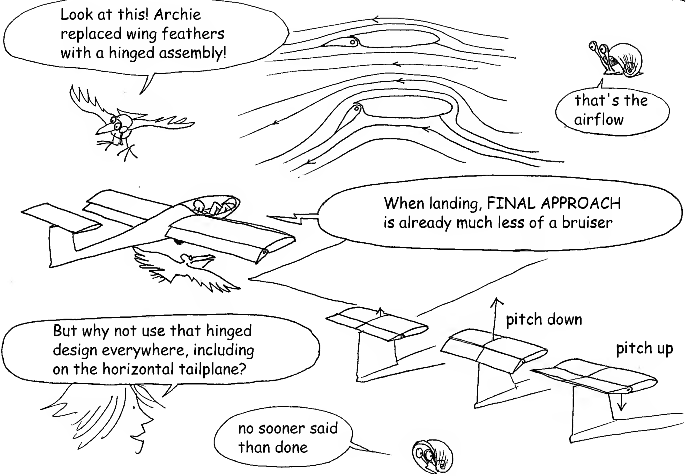

if I want to design an efficient **SAILPLANE**, I have to get rid of all sources of energy waste, **TURBULENCE** first and foremost. If my sailplane leaves behind a lot of air set in motion in its wake, that's wasted energy
logical...
all these cables are the source of significant **DRAG**: remove them. The pilot: inside the structure. Smooth walls, without protrusions. Everything needs redesigning
that's not bad. But how do I fly this machine?
I can move back and forth in the cockpit to climb or dive. I installed windows on both sides, and by sticking out my hand I can turn. But it's not very efficient and it causes turbulence, which is exactly what I want to avoid at all cost


I stick my hand out to turn left. Hmm, not very efficient!
By the way...
f
Now that's interesting. When I stick out my hand that way, kind of like a wing, and I change its ANGLE OF ATTACK α, the force changes by the same ratio as the angle. Let's rig a horizontal tailplane with an angle of attack α I can change at will
axis
pitch up
angle of attack α negative
thanks to these ACTUATING RODS, Archie can remotely control the horizontal tailplane of his flying machine using a JOYSTICK
pitch down
angle of attack α positive
Awesome!

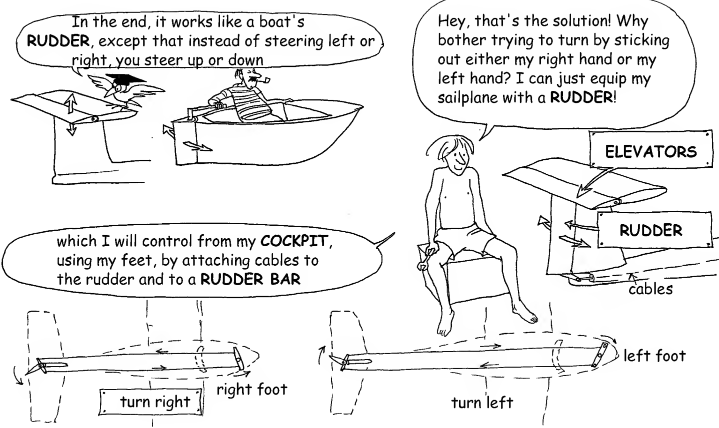


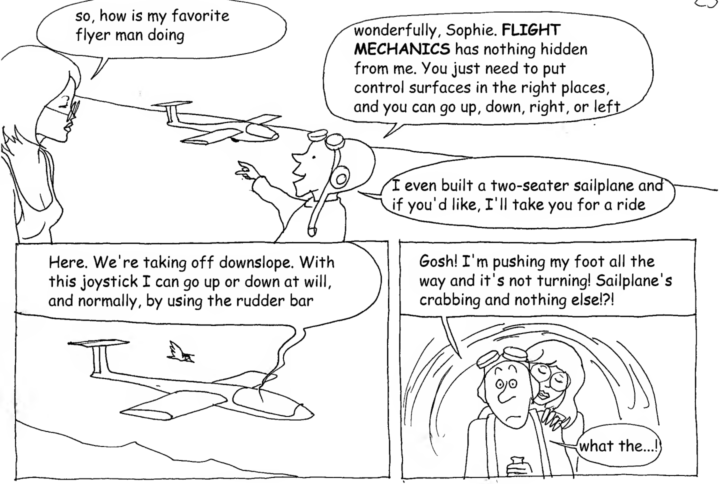
The faster a sailplane goes, the louder and more audible the noise from wing friction becomes. Before speed meters were invented, sailplane pilots could be recognized at their elongated ears, from adaptation

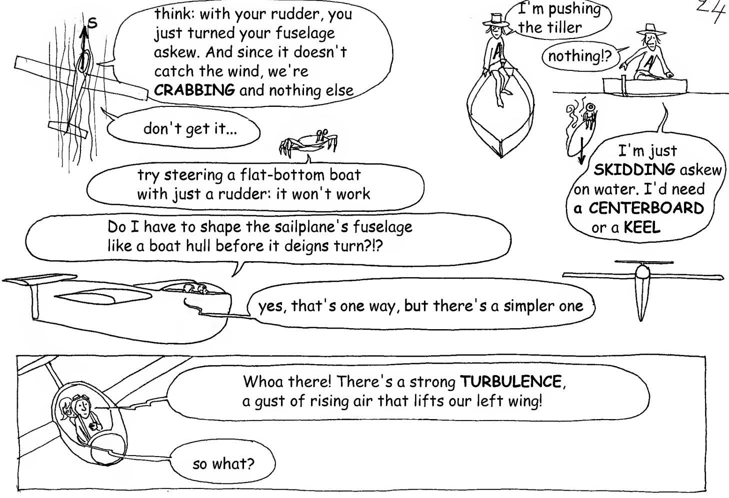

WING FLAPS
OK, PITCH control works well enough. But turning isn't anywhere near ready. Meanwhile, I'm going to watch birds, see how they fly
there!
F
V
F
V
V
V
At the time they land they curve their wings by pulling on the feathers using muscles
By increasing the curvature of my AIRFOIL, the aerodynamic force the wing creates becomes higher for the same speed S. Conversely, by shaping their wings this way, birds can APPROACH at a lower speed
I cannot bend these wings. However, I can attach the back part using hinges
wings with... hinges!?!

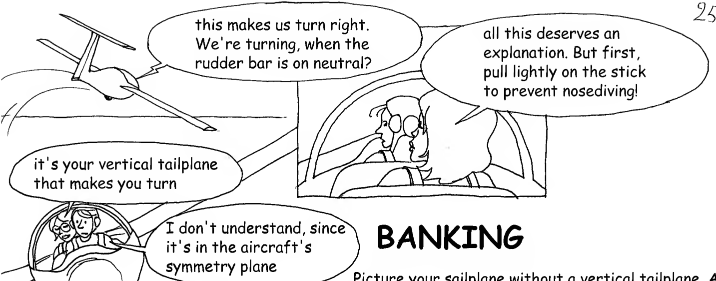

Look at this! Archie replaced wing feathers with a hinged assembly!
that's the airflow
When landing, FINAL APPROACH is already much less of a bruiser
pitch down
pitch up
But why not use that hinged design everywhere, including on the horizontal tailplane?
no sooner said than done

CONTROL SURFACES

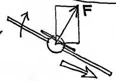



so, how is my favorite flyer man doing
wonderfully, Sophie. FLIGHT MECHANICS has nothing hidden from me. You just need to put control surfaces in the right places, and you can go up, down, right, or left
I even built a two-seater sailplane and if you'd like, I'll take you for a ride
Here. We're taking off downslope. With this joystick I can go up or down at will, and normally, by using the rudder bar
Gosh! I'm pushing my foot all the way and it's not turning! Sailplane's crabbing and nothing else!?!
what the...!

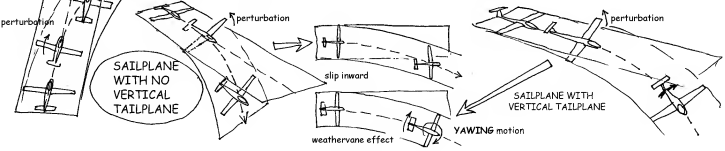

S
think: with your rudder, you just turned your fuselage askew. And since it doesn't catch the wind, we're **CRABBING** and nothing else
don't get it...
try steering a flat-bottom boat with just a rudder: it won't work
I'm pushing the tiller
nothing!?
I'm just **SKIDDING** askew on water. I'd need **a CENTERBOARD** or a **KEEL**
Do I have to shape the sailplane's fuselage like a boat hull before it deigns turn?!?
yes, that's one way, but there's a simpler one
Whoa there! There's a strong **TURBULENCE**, a gust of rising air that lifts our left wing!
so what?

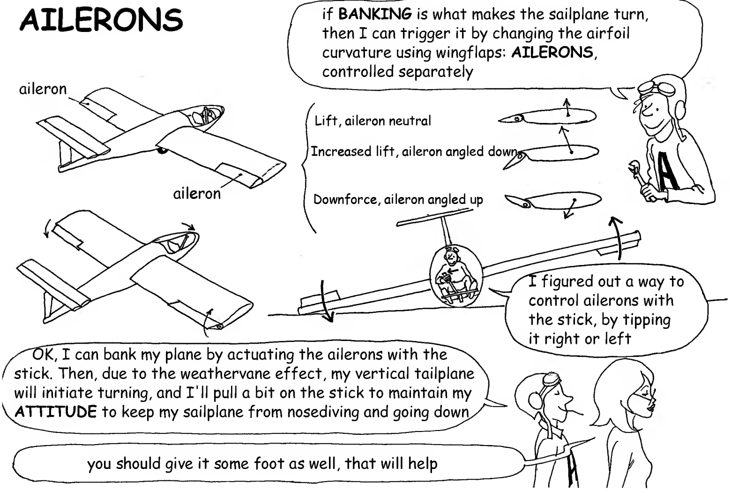


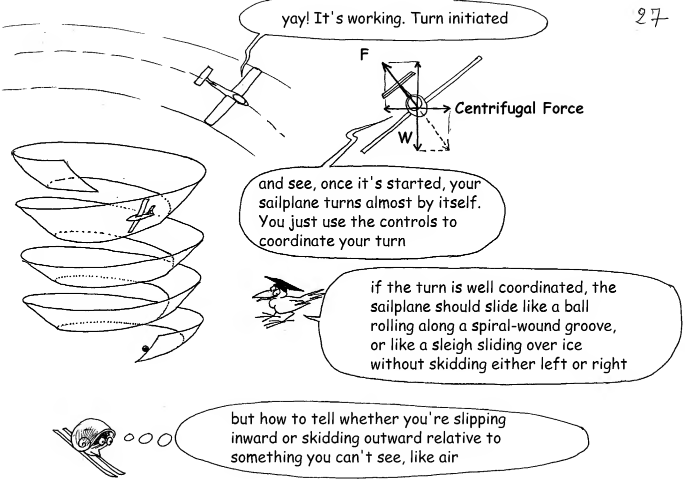
BANKING



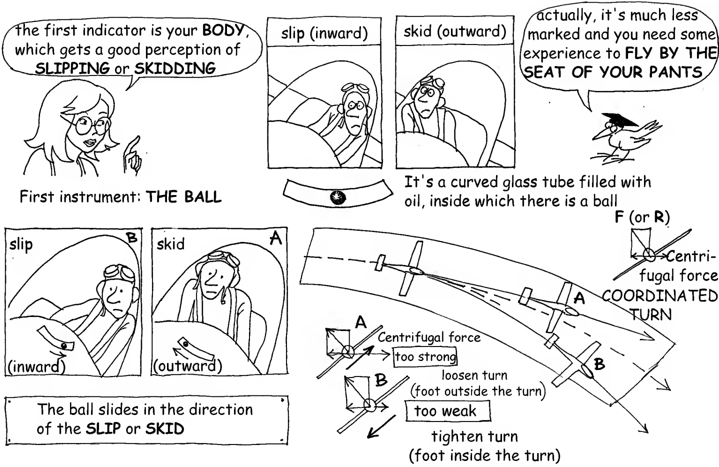
Picture your sailplane without a vertical tailplane. A gust of rising air lifts the left wing. our sailplane will start **SLIPPING INWARD** but without **YAWING**. However, with the vertical tailplane in place, the **WEATHERVANE EFFECT** will tend to align the fuselage with the direction of motion:

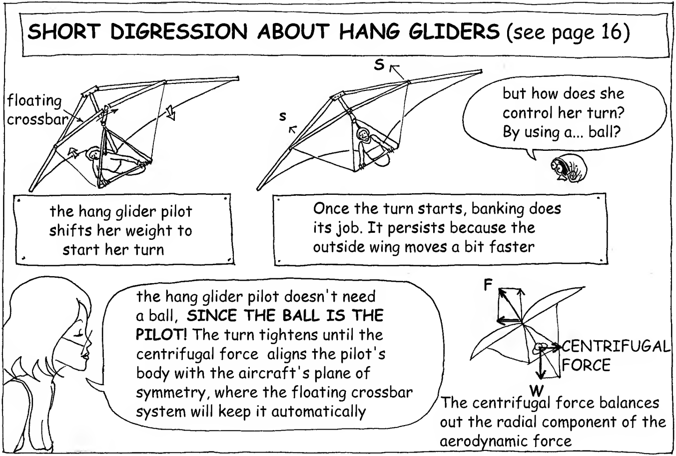



AILERONS
if BANKING is what makes the sailplane turn, then I can trigger it by changing the airfoil curvature using wingflaps: AILERONS, controlled separately
aileron
aileron
Lift, aileron neutral
Increased lift, aileron angled down
Downforce, aileron angled up
I figured out a way to control ailerons with the stick, by tipping it right or left
OK, I can bank my plane by actuating the ailerons with the stick. Then, due to the weathervane effect, my vertical tailplane will initiate turning, and I'll pull a bit on the stick to maintain my ATTITUDE to keep my sailplane from nosediving and going down
you should give it some foot as well, that will help

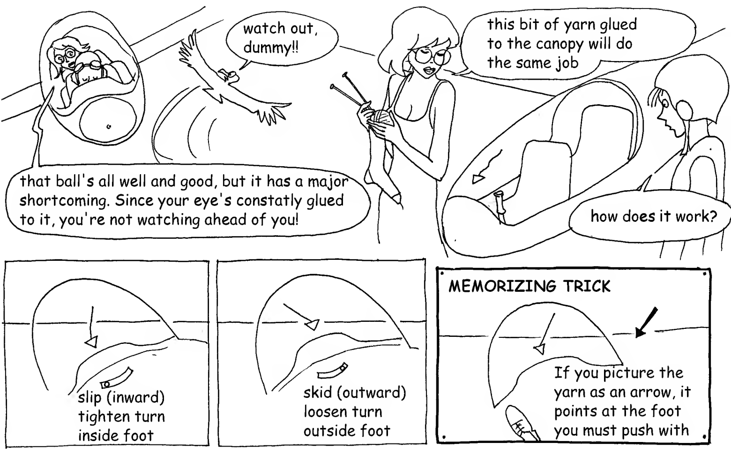

yay! It's working. Turn initiated
F
Centrifugal Force
W
and see, once it's started, your sailplane turns almost by itself. You just use the controls to coordinate your turn
if the turn is well coordinated, the sailplane should slide like a ball rolling along a spiral-wound groove, or like a sleigh sliding over ice without skidding either left or right
but how to tell whether you're slipping inward or skidding outward relative to something you can't see, like air

TURN CONTROL

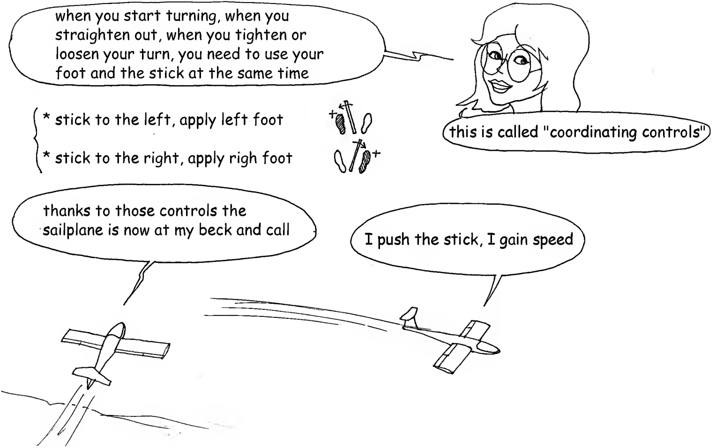



SHORT DIGRESSION ABOUT HANG GLIDERS (see page 16)
floating crossbar
the hang glider pilot shifts her weight to start her turn
S
s
Once the turn starts, banking does its job. It persists because the outside wing moves a bit faster
but how does she control her turn? By using a... ball?
the hang glider pilot doesn't need a ball, SINCE THE BALL IS THE PILOT! The turn tightens until the centrifugal force aligns the pilot's body with the aircraft's plane of symmetry, where the floating crossbar system will keep it automatically
F
CENTRIFUGAL FORCE
W
The centrifugal force balances out the radial component of the aerodynamic force

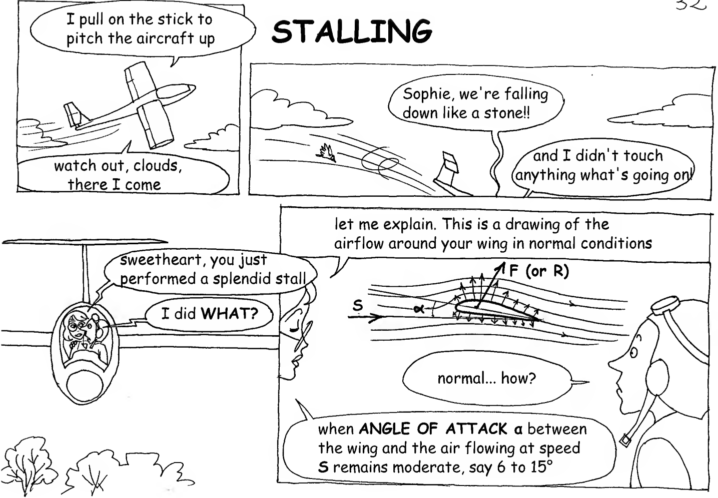
THE WOOL YARN



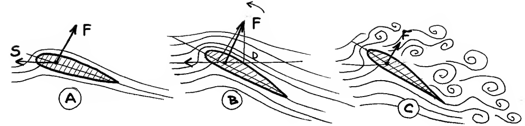
COORDINATING CONTROLS



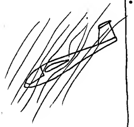
STALLING



I pull on the stick to pitch the aircraft up
watch out, clouds, there I come
Sophie, we're falling down like a stone!!
and I didn't touch anything what's going on!
sweetheart, you just performed a splendid stall
I did WHAT?
let me explain. This is a drawing of the airflow around your wing in normal conditions
F (or R)
S
α
normal... how?
when ANGLE OF ATTACK α between the wing and the air flowing at speed S remains moderate, say 6 to 15°

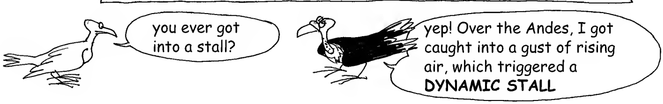


- On diagram **A**, a normal flight position
- On diagram **B**, flight at a high angle of attack. The aerodynamic force's projection onto the direction of speed **S** still provides drag **D**, but the forward tilt of force **F** makes it project <u>forward</u> on the wing's plane
- On diagram **C**, air can no longer go around the wing's leading edge. Due to centrifugal force, the airstream **SEPARATES**. Lift collapses. The sailplane "waves" and nosedives

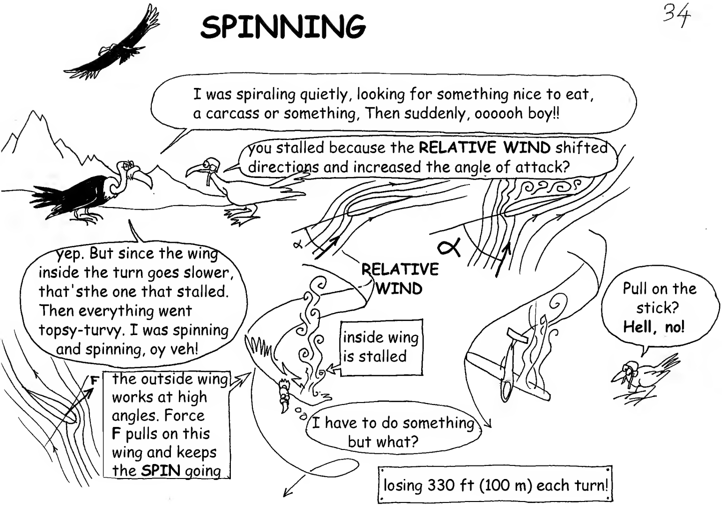


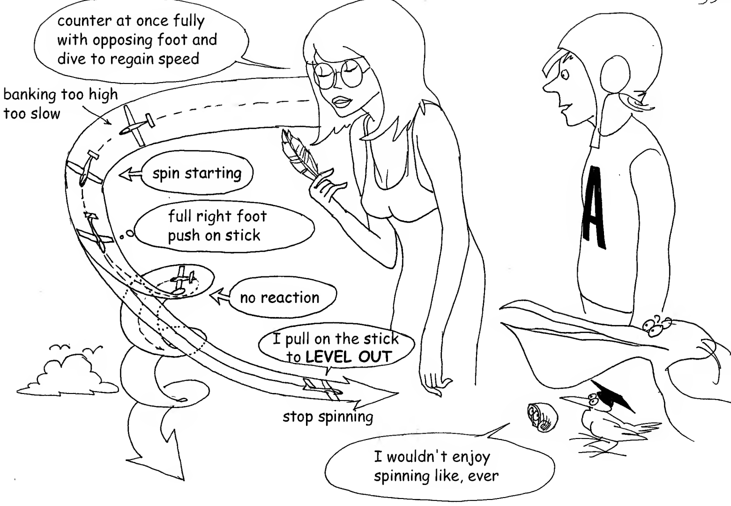
After a **DIVE** the sailplane gathers speed again by itself. The airflow again becomes **ATTACHED** to the airfoil. Lift returns suddenly, because of the increase in speed **S**. When the pilot feels the sailplane is stalling or sinking, she can return to a normal configuration faster by pitching down slightly, by pushing the stick forward, by **LETTING GO**

The Management

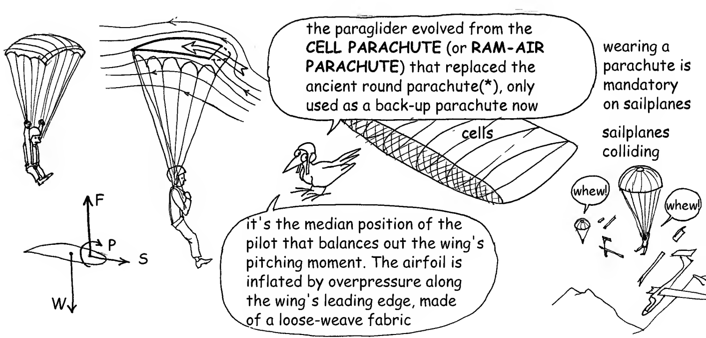


SPINNING

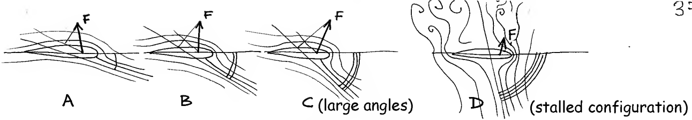

I was spiraling quietly, looking for something nice to eat, a carcass or something, Then suddenly, oooooh boy!!
you stalled because the **RELATIVE WIND** shifted directions and increased the angle of attack?
α
α
RELATIVE WIND
yep. But since the wing inside the turn goes slower, that'sthe one that stalled. Then everything went topsy-turvy. I was spinning and spinning, oy veh!
inside wing is stalled
Pull on the stick? **Hell, no!**
F
the outside wing works at high angles. Force **F** pulls on this wing and keeps the **SPIN** going
I have to do something but what?
losing 330 ft (100 m) each turn!


counter at once fully
with opposing foot and
dive to regain speed
banking too high
too slow
spin starting
full right foot
push on stick
no reaction
I pull on the stick
to **LEVEL OUT**
stop spinning
I wouldn't enjoy
spinning like, ever

PARAGLIDER: WHEN THE SAIL CAN BECOME A SHROUD



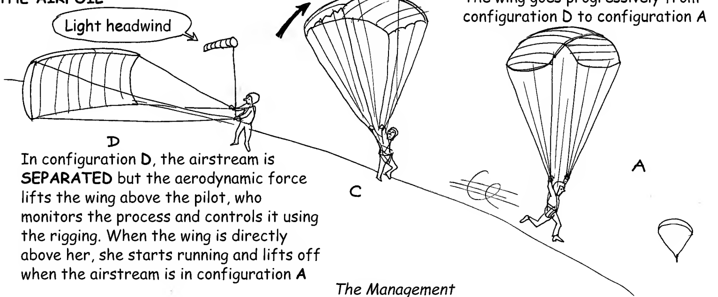
(*) Vertical descent rate is 19.5 ft/s (6 m/s). Descent rate of a cell parachute: 8 ft/s (2.5 m/s)



It's well-known that as the angle of attack (the direction of **RELATIVE WIND**) increases, the aerodynamic force applied to the wing's **AERODYNAMIC CENTER**, 25% along the **CHORD**, tilts forward progressively. The airstream eventually **SEPARATES**. The force decreases, but remains directed **FORWARD RELATIVE TO THE AIRFOIL**

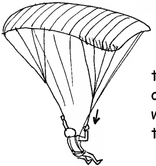
TAKING OFF IN A PARAGLIDER

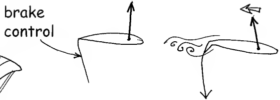
The wing goes progressively from configuration **D** to configuration **A**

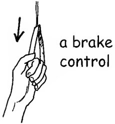


In configuration **D**, the airstream is **SEPARATED** but the aerodynamic force lifts the wing above the pilot, who monitors the process and controls it using the rigging. When the wing is directly above her, she starts running and lifts off when the airstream is in configuration **A**

The Management

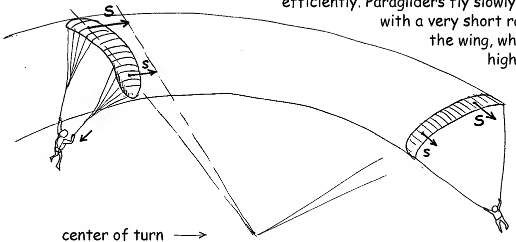




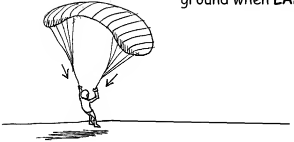


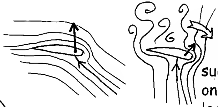
the paraglider pilot acts on the drag of the right and left halves of her wing, whose trailing edges are attached to control strings called **BRAKES**

Here, the pilot is pulling on her right brake. She increases the **DRAG** of the right half of her sail. This starts her turning very efficiently. Paragliders fly slowly and can easily turn with a very short radius. The outside of the wing, which goes faster, rises higher (**INDUCED ROLL**)



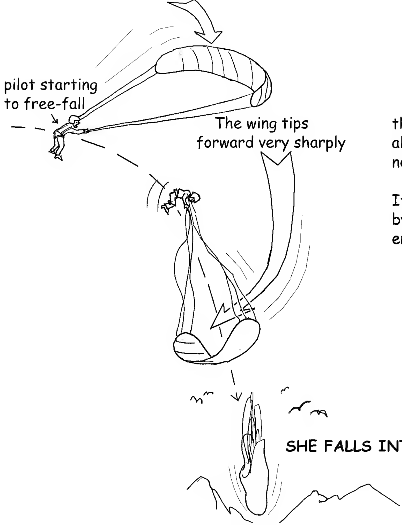
By pulling on both brakes at the same time, she can slow down her wing to the **STALL SPEED**. She'll perform that maneuver right before touching the ground when **LANDING**, to cancel her speed





But other than that, this maneuver is **VERY DANGEROUS**. It may also be caused by a strong **GUST OF RISING AIR** triggering a **DYNAMIC STALL**

Dynamic stall flying in **TURBULENT AIR** during the middle of the day



the tilt of the aerodynamic force forward along the airfoil pushes the wing (with its nearly-nil inertia) forward very fast

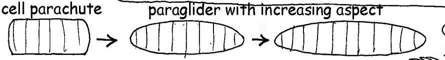
If the pilot doesn't counter that motion (*) by braking the wing immediately, the wing ends up under her

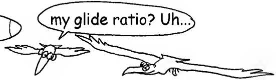
SHE FALLS INTO IT AND DIES

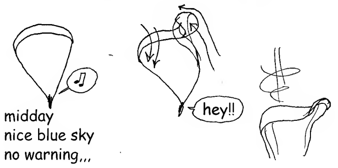
(*) An <u>inexperienced</u> beginner, however, will tend to... let go of everything!

If the incident occurs near ground level and the paraglider pilot is lucky enough not to end up inside her wing, a very sharp recovery may cause her to touch the ground very hard

In aerial sports, there's a trade-off to be found between **PERFORMANCE** and **SAFETY**. A flat airfoil allows higher speed, which is desirable to fly from one thermal to the next. But the flatter the airfoil, the sharper the stall. Designers also attempt to increase the **GLIDE RATIO**(*) (more on which later) by increasing the paraglider's **ASPECT**, thus making it vulnerable to **WING COLLAPSE** in **TURBULENT AIR**, *which translate to altitude loss of at least* **164 ft (50 m)** before the wing **REOPENS**

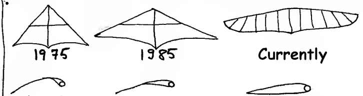




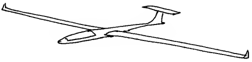


(*) From height **h** you can fly to distance **d** = **g** × **h**, **g** being the **GLIDE RATIO**

this performance race also affects the hang-gliding world



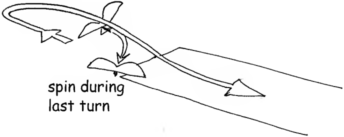
1975	1985	Currently
single surface		double surface (with battens)
16 miles/hr (25 km/hr)	19-47 miles/hr (30-75 km/hr)	25-62 miles/hr (40-100 km/hr)
glide ratio 3	glide ratio 7	glide ratio 10
8.2 ft/s (2.5 m/s)	5.9 ft/s (1.8 m/s)	3.3 ft/s (1 m/s)



A good compromise is needed between performance and safety. The first hang gliders <u>would never</u> stall asymmetrically. Modern hang gliders, with their high aspect ratios and biconvex airfoils, behave as classical wings, and if stalling in a turn, can start **SPINNING**

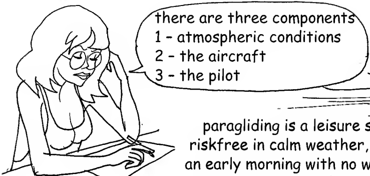
20 ft/s (6 m/s)
parachute-like fall

turn into final approach

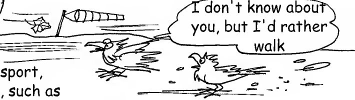


early hang gliders could serve as parachutes when falling straight down

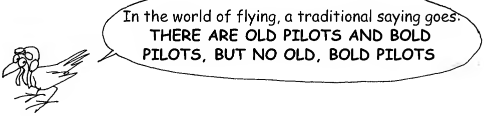
FLIGHT ENVELOPE



There are atmospheric conditions that preclude flying for certain aircraft



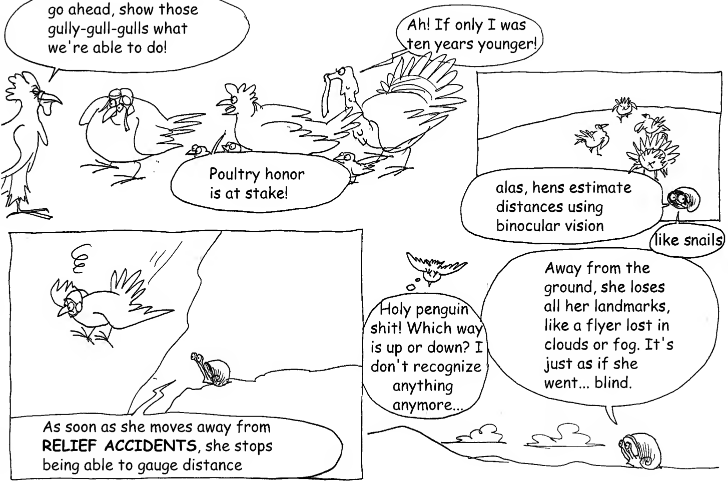
paragliding is a leisure sport, riskfree in calm weather, such as an early morning with no wind or turbulent air. In turbulent air, risk is always present. Aircraft that look alike can have very different flight envelopes. Some are forgiving, others not so. Performance race, that disease of today's world, favors risk-taking.



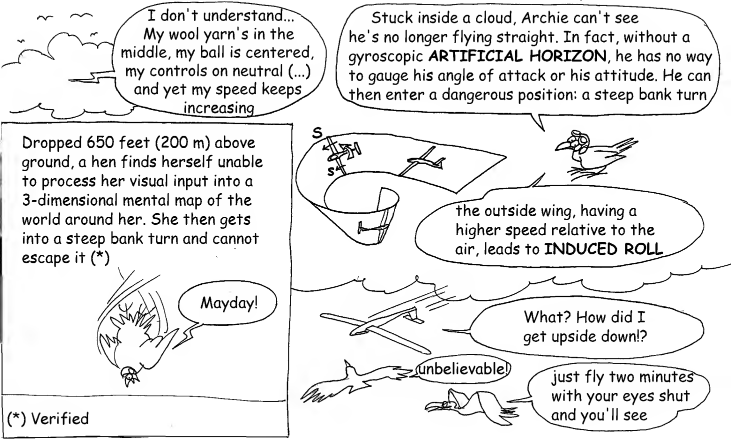

that's really nice. Using this road, we can take the sailplane up to 1600 feet (500 m) above the plain
stick, wool yarn, that's all woman's stuff
There, we're at the top. But which way should we take off?
into the wind. When getting up to speed, we get that for free
wind direction? There's the traditional wet-your-finger trick
wait, I have an idea. In this heat, I'll feel better wearing short sleeves. Go get me a stick
Lenny, don't you think you're going too far?

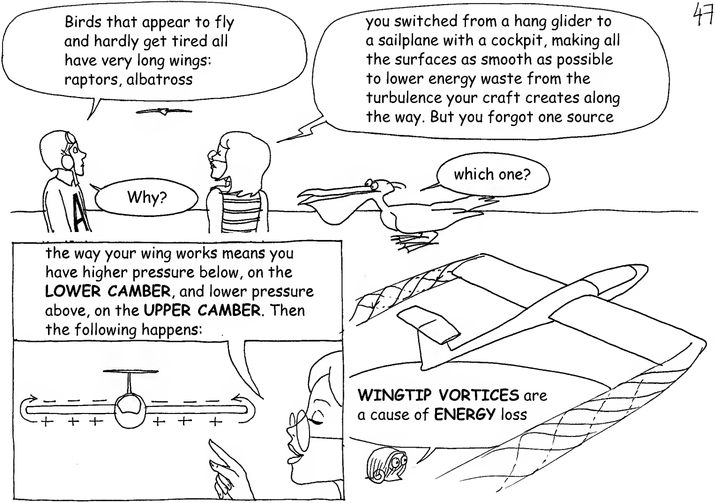
WINDSOCKS

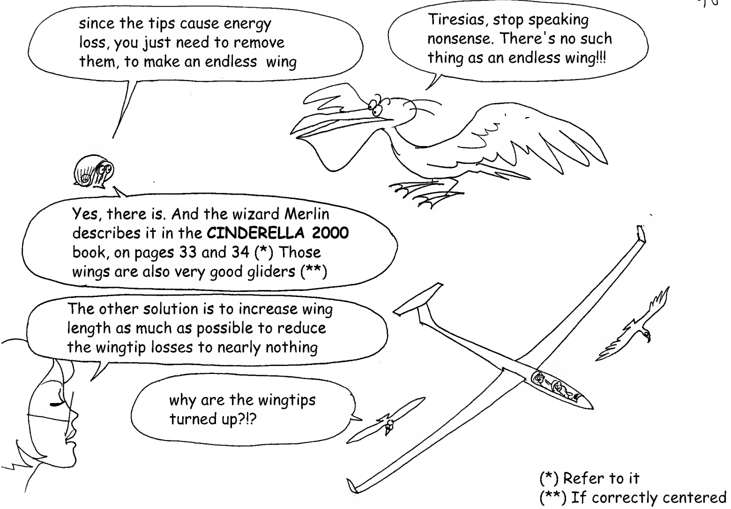

see? What did I tell you?
come here, it's a good spot
Not all birds are built from the same plan. Some appear to fly barely flapping their wings. And then there's others, like hens...
just because you have large wings doesn't mean you can show off. If we had room underneath, we could do as well as you
Riiiight...
there's a cliff over there, let's see how well you do


go ahead, show those gully-gull-gulls what we're able to do!
Ah! If only I was ten years younger!
Poultry honor is at stake!
alas, hens estimate distances using binocular vision
like snails
As soon as she moves away from **RELIEF ACCIDENTS**, she stops being able to gauge distance
Holy penguin shit! Which way is up or down? I don't recognize anything anymore...
Away from the ground, she loses all her landmarks, like a flyer lost in clouds or fog. It's just as if she went... blind.

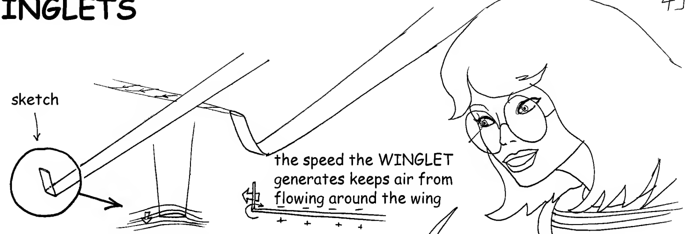
STEEP BANK TURN



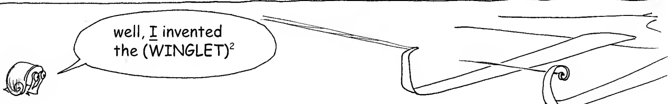

Birds that appear to fly and hardly get tired all have very long wings: raptors, albatross
you switched from a hang glider to a sailplane with a cockpit, making all the surfaces as smooth as possible to lower energy waste from the turbulence your craft creates along the way. But you forgot one source
Why?
which one?
the way your wing works means you have higher pressure below, on the **LOWER CAMBER**, and lower pressure above, on the **UPPER CAMBER**. Then the following happens:
WINGTIP VORTICES are a cause of **ENERGY** loss

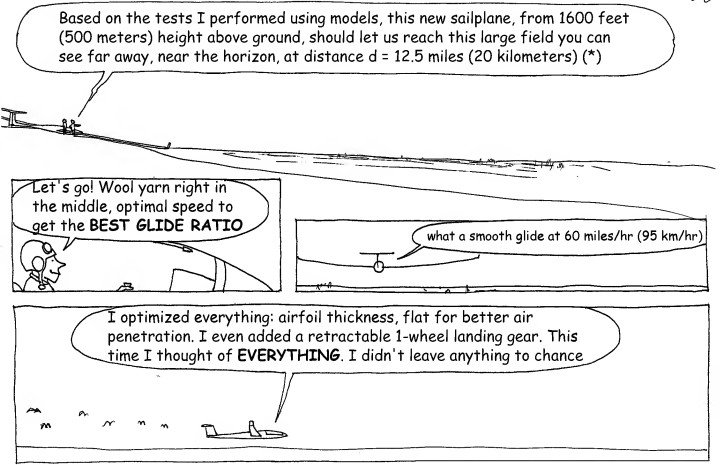

since the tips cause energy loss, you just need to remove them, to make an endless wing
Tiresias, stop speaking nonsense. There's no such thing as an endless wing!!!
Yes, there is. And the wizard Merlin describes it in the **CINDERELLA 2000** book, on pages 33 and 34 (*) Those wings are also very good gliders (**)
The other solution is to increase wing length as much as possible to reduce the wingtip losses to nearly nothing
why are the wingtips turned up?!?
(*) Refer to it
(**) If correctly centered

WINGLETS

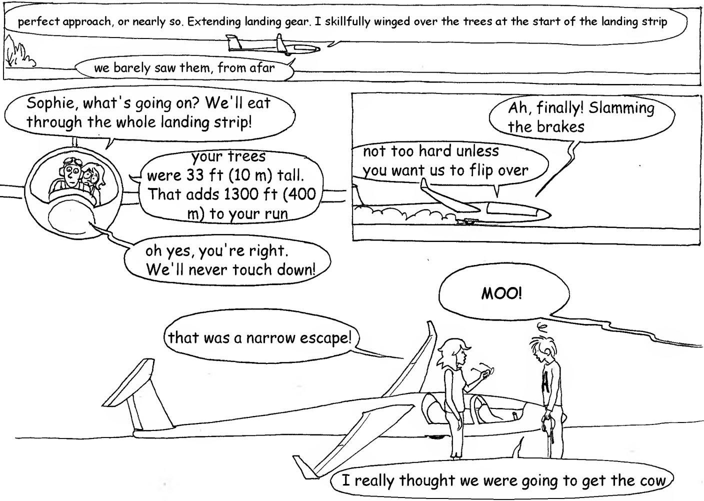


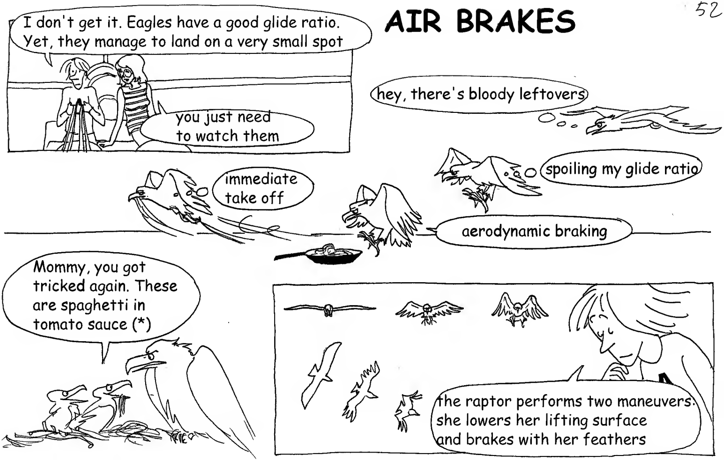
In a nutshell, **WINGLETS** are mini-wings perpendicular to the main wing, such that their airfoil generates a (low) **INDUCED SPEED** that prevents air from flowing around the wing, due to the pressure difference between lower camber and upper camber. Winglets create their own wingtip vortices, but the gain is so obvious that this idea, which might have emerged a century ago, is now progressively gaining ground throughout the aeronautics world.



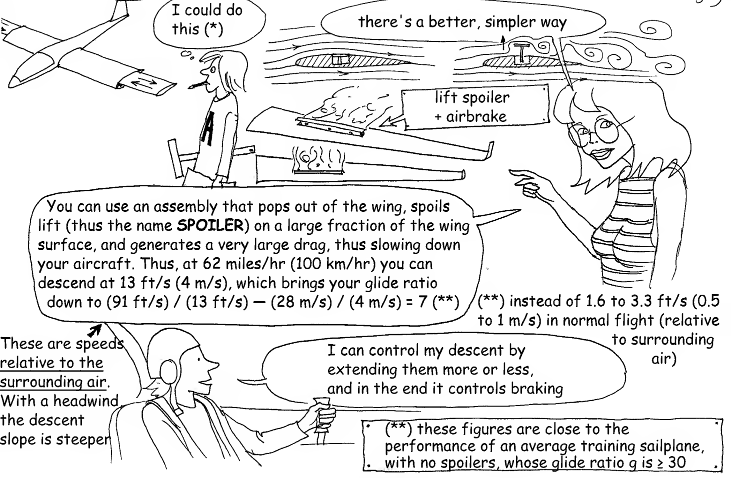


(*) which translates to a GLIDE RATIO of d / h = 40. But some sailplanes do better than 60 (descent slope = 1 degree)


perfect approach, or nearly so. Extending landing gear. I skillfully winged over the trees at the start of the landing strip
we barely saw them, from afar
Sophie, what's going on? We'll eat through the whole landing strip!
your trees were 33 ft (10 m) tall. That adds 1300 ft (400 m) to your run
oh yes, you're right. We'll never touch down!
Ah, finally! Slamming the brakes
not too hard unless you want us to flip over
MOO!
that was a narrow escape!
I really thought we were going to get the cow



(*) This happened to the author in Camp Simba at the Ngoro Ngoro crater in Tanzania back when he was a safari guide in Africa



(*) this was tried on airplanes in the 1930s, with limited success